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CRREL

Laboratory and Field Tests of a Wire Mesh Frazil Collector

Edward P. Foltyn

October 1990

Special Report 90-35

U.S. Army Corps
of Engineers
Cold Regions Research &
Engineering Laboratory

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RIM
RIVER ICE MANAGEMENT

Prepared for
OFFICE OF THE CHIEF OF ENGINEERS

PREFACE

This report was prepared by Edward P. Foltyn, Research Hydraulic Engineer, Ice Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. The investigation was conducted under the Construction, Operations, and Maintenance research area of the River Ice Management (RIM) research program as part of Work Unit 32284, *Ice Control Structures*.

This report was technically reviewed by Dr. Jean-Claude Tatinclaux and Kathleen Axelson of CRREL.

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CONTENTS

	Page
Preface	ii
Conversion factors	iv
Introduction	1
Laboratory tests	2
Field tests	4
Site description	4
Winter 1985–86	5
Winter 1986–87	6
Conclusions	9
Future research	9
Literature cited	10
Abstract	11

ILLUSTRATIONS

Figure		
1.	Vertical and inclined faces used in laboratory testing of wire mesh frazil collectors	2
2.	Views of wire mesh frazil collector in flume	2
3.	Laboratory test results	3
4.	Test structure in Illinois River near Marseilles, Illinois	4
5.	Upper Salmon River from Deadwater Reach to Challis, Idaho	4
6.	Artist's conception of proposed ice-control structure	5
7.	Location of test structures in Salmon, Idaho	5
8.	Accumulation of frazil ice on expanded sheet metal test structure	6
9.	Chain link fence structure with little frazil ice accumulation	6
10.	Details of one panel of wire mesh frazil collector	7
11.	Measured air and water temperatures in the Salmon River in Salmon, Idaho	8
12.	Measured air temperatures at Salmon, Idaho, and measured tensile loads on wire mesh frazil collector	9
13.	Wire mesh frazil collector with floating ice boom in the Salmon River in Salmon, Idaho	9

CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM *Metric Practice Guide* (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	*By*	*To obtain*
inch	25.4	millimeter
foot	0.3048	meter
foot/second	0.3048	meter/second
pound (mass)	0.4535924	kilogram
pound/foot	14.59390	newton/meter
gallon/minute	0.00006309020	$meter^3$/second
degree Fahrenheit	$t°C = (t°F-32)/1.8$	degree Celsius

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EDWARD P. FOLTYN

INTRODUCTION

Ice jams on rivers cause problems that range from slowing commercial river traffic to widespread flooding. Most freezeup jams are frazil ice accumulations created when frazil slush, pans or floes drift to a barrier, whether man-made (i.e., a dam) or natural (i.e., a channel constriction or existing ice cover), where the frazil ice is stopped. When the frazil ice is stopped on the surface by the barrier, an ice cover will form, and it will progress upstream by juxtaposition. Some of the frazil may also be swept beneath the leading edge of the cover and be deposited on the underside of the cover. This type of ice accumulation is known as a hanging dam.

The accumulation will progress upstream as long as there is a sufficient ice supply or until the drag and gravitational forces acting on the cover are greater than the internal compressive strength of the cover. When the cover's strength is exceeded, it will shove, collapse and thicken until it can again support the drag and gravitational forces. Jams of considerable depth are formed by this process.

One technique of controlling frazil ice jams is to reduce the supply of frazil ice feeding a jam. This can be accomplished through the use of a dam or weir structure placed upstream of the jam site. A dam or weir will increase the flow depth, with a resulting decrease in flow velocity. When the velocity decreases to a critical value, about 2.3 ft/s, a sheet ice cover can form by juxtaposition, which insulates the water from further heat loss, thereby reducing formation of frazil ice and trapping incoming ice floes (Michel 1971, Perham 1983).

Two sites that are currently under study by CRREL are perfect examples of such a problem. An annual ice jam downstream of the Marseilles Lock on the Illinois River leads to serious navigation problems (Foltyn 1985). Tow-boat operators and lock personnel have indicated that it is not unusual to spend 10–18 hours navigating through this $^1/_2$- to $^3/_4$-mile long jam. Ice jams on the Salmon River have caused flood related damages to the City of Salmon, Idaho, at least 32 times since 1900. The latest and most costly ice-related flooding occurred in 1984, with monetary losses exceeding $1.8 million.

Ice jam formation and, therefore, the solution to ice jamming is usually site specific. However, the two particular jams mentioned above have common aspects so that the proposed solutions for the two sites are variations of the same basic concept. The ice jams at both sites are created by large accumulations of frazil ice generated in river rapids and fast flowing reaches upstream from the jam locations. At both sites, environmental and recreational concerns preclude the use of permanent structures to correct the problems. The primary difference between the two sites is the width of the river reach where ice jam control structures may be installed, namely 650 ft at the Marseilles site and 300 ft on the Salmon River.

With concerns for fish passage and the recreational aspects at both Marseilles and Salmon in mind, we felt that the only permissible solution was a structure that could be completely closed off in the winter only. One such solution proposed by Earickson and Gooch (1986) for Salmon consisted of a series of concrete piers and a concrete apron extending across the channel. During most of the year, the openings between the piers would remain unobstructed to allow passage of fish and boaters. In the winter months, typically December through February, the openings would be blocked off to form a weir. The openings can be blocked off with either a solid barrier, such as stop logs or a bascule gate, or an initially permeable structure that clogs with ice to form the barrier.

We have developed the idea of using an initially permeable barrier through our observations of trash

rack freezeup and clogging (Foltyn 1986). When water reaches a temperature of only a few thousandths of a degree below freezing, frazil ice that is very "sticky" will be generated. This is known as active frazil ice. As active frazil ice adheres to the wire mesh, the openings in the wire mesh close down. The mesh will also mechanically clog with frazil floes, brash ice or pieces of broken shore ice lodging against it. The end result is clogging of the structure, making it nearly impermeable. We feel that this technique will work to an upper limit of 6 ft/s of flow velocity. This is based on previous work by Michel et al. (1984), who have shown that the active frazil accumulations were limited to 2 in. of growth when the flow velocities are 6 ft/s, while there were no accumulations above that level.

This report describes the laboratory and field testing of a wire mesh frazil collector. It looks at the intended function of the structure, compares the design and actual loads that an experimental structure experienced, and explains discrepancies between them.

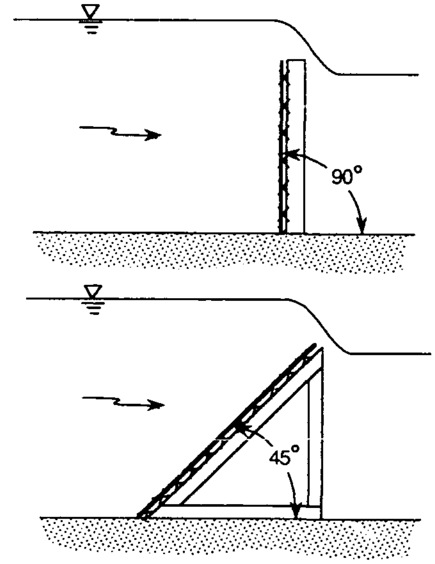


Figure 1. Vertical and inclined faces used in laboratory testing of wire mesh frazil collectors.

LABORATORY TESTS

A series of laboratory tests was conducted in CRREL's refrigerated flume facility (Daly et al. 1985) during August and September of 1985 to test the feasibility of a wire mesh frazil collector.

Two types of wire mesh were tested: an expanded sheet metal with opening dimensions of 3 × 1.5 in. along the major and minor diagonals and a chain link fence fabric with 2.25- × 2.25-in. openings.

Two different structural shapes were tested. The prototype structure was envisioned as a rigid frame to support the wire mesh and the resulting hydrodynamic load. To resist this load, both a box-shaped and a triangular-shaped cross section were used to examine a vertical and an inclined face for the wire mesh (Fig. 1).

A series of nine laboratory experiments was run in the refrigerated flume (Fig. 2) to study the optimum structure orientation and trapping efficiency of the wire mesh. After the first test, we noted that a floating ice boom upstream of the frazil collector would assist in stabilizing an ice cover and would help maintain the integrity of the cover for a longer period. Without a boom, the ice cover in the laboratory flume took $2^1/_2$ times as long to form as it did with a boom.

The head loss through the structure is a function of the amount of clogging, and the effectiveness of the frazil collector was determined by measuring the headwater and tailwater elevations with point gauges. In addition time-lapse videography was taken as a visual record of the tests.

a. Upstream. *b. Downstream.*

Figure 2. Views of wire mesh frazil collector in flume.

The measurements of laboratory tests 6–9 are presented versus time in Figure 3. The graphs show the pool depth 10 ft upstream of the structure and that of the tailwater box, 13 ft downstream, as well as the discharge variation. The tests were generally run at 280 to 300 gal./min, with the ambient air temperature at 0°F.

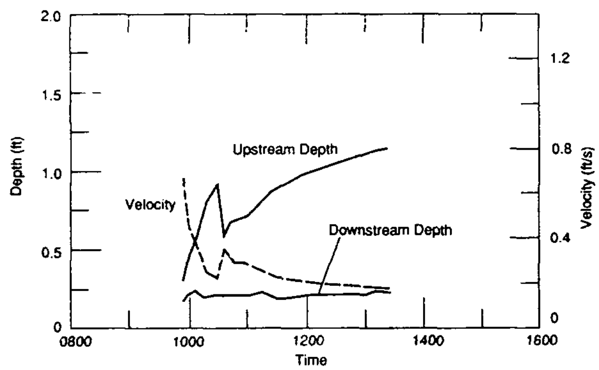
Figure 3a shows the depth measurements for a test structure of chain link fence with the face inclined at 45°. The upper pool elevation dropped at 1020 hours (30 minutes after the start of the test) because the ice dam failed near the right bank. The 45° configuration allows a force component of the water to act tangentially to the face, which tends to wash the ice off. All tests were then made with vertical structures.

During test 7, flow was increased to 1850 gal./min to determine the stability of the ice dam and cover. As can be seen in Figure 3b, when the flow was increased (at 1300 hours) the upstream pool level dropped slightly until the ice cover failed and clogged the wire mesh weir again. As the flow was increased to 1850 gal./min the cover eventually failed.

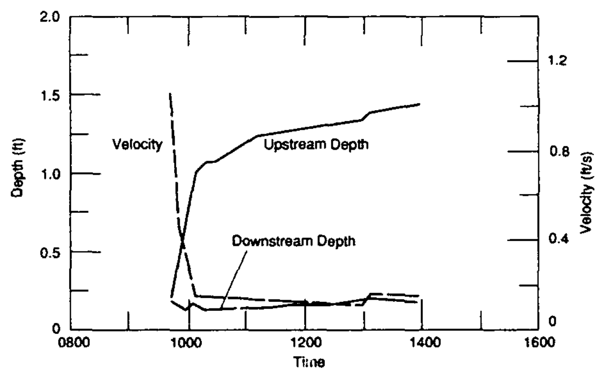
Figure 3c shows the upstream and downstream pool levels resulting from a test structure with a vertical face of chain link fence extending above the initial waterline. With this configuration the cover remained stable after the mesh iced up.

Figure 3d shows the results of a configuration with a vertical face that was submerged at the beginning of the test. The upper pool decreased at 0940 hours because the weir flow over the dam eroded part of the crest, allowing the flow to accelerate through the breach in the crest. Although the pool level eventually built back up, this test indicates that a vertical face extending above the waterline builds a dam quicker and that the resulting dam and cover are more stable.

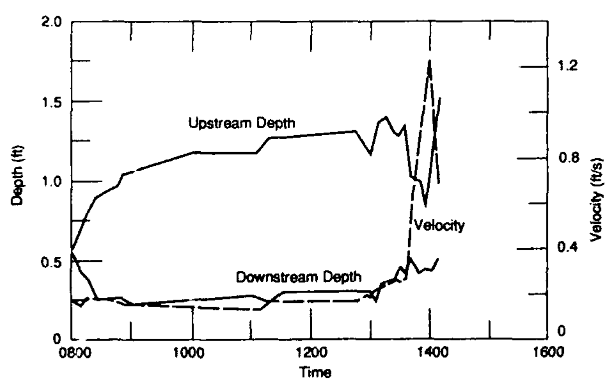
The results of the laboratory tests indicated that the structure should extend above the water surface to help trap the incoming floes more efficiently. In addition we learned that a floating ice boom placed upstream of the structure would extend the period that the cover would remain in place. Also, a vertical structure was more efficient at trapping frazil ice than an inclined one. These



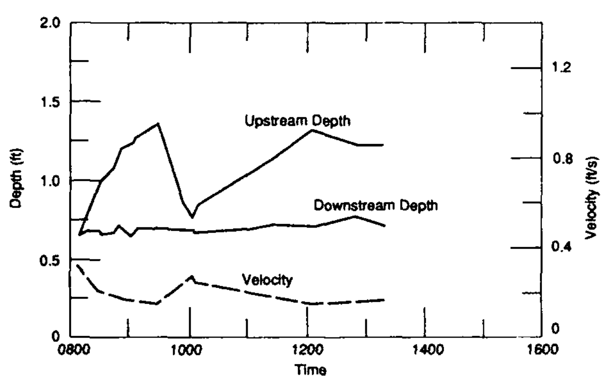
a. Test 6 (chain link fence, 45° inclined face, extended above waterline, T_a = 0°F [−18°C]).



c. Test 8 (chain link fence, vertical face, extended above waterline, T_a = 0°F [−18°C]).



b. Test 7 (expanded sheet metal, vertical face, extended above waterline, T_a = 0°F [−18°C]).



d. Test 9 (chain link fence, submerged vertical face, T_a = 0°F [−18°C]).

Figure 3. Laboratory test results.

tests showed no appreciable difference in the time of clogging between chain link fence fabric and expanded sheet metal when a vertical face was used.

FIELD TESTS

On completion of the laboratory testing of the frazil collectors, a series of field tests was planned for the winter of 1985–86 and repeated in 1986–87. The tests were to be conducted at Salmon, Idaho, and Marseilles, Illinois. However, because of the warm weather in the 1985–86 winter, the test program at Marseilles was cancelled. A test structure was installed at Marseilles in January 1987 in time for the January cold snap. The test structure, as seen in Figure 4, is 30 ft long and 5 ft high. It was instrumented to measure loads, water velocity, air and water temperatures. Unfortunately, because of the operation of the gates at Marseilles Dam, there was only 0.5 ft of water at the test location. Therefore, the only field tests that yielded useful results were those conducted at Salmon, Idaho.

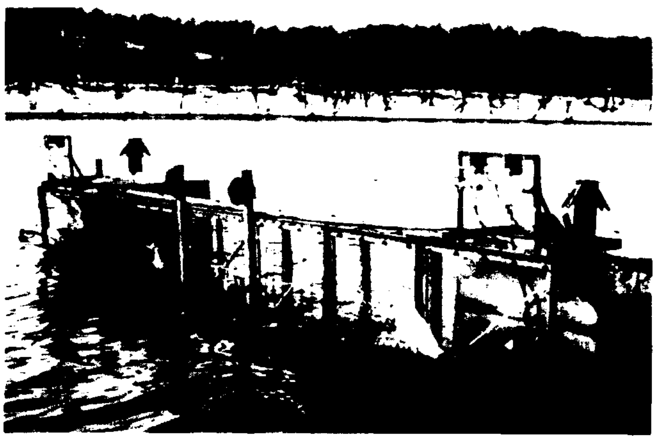


Figure 4. Test structure in Illinois River near Marseilles, Illinois.

Site description

A location where CRREL has been studying ice control structures is the Salmon River near Salmon, Idaho. The Salmon River flows approximately 400 miles (645 km) from its headwaters in the Sawtooth National Recreation Area of south-central Idaho to its confluence with the Snake River. From its source, the river flows in generally a northward direction through the City of Salmon located at River Mile (RM) 260 to the community of North Fork at RM 238 (Fig. 5). From here the river turns west and flows through the Deadwa-

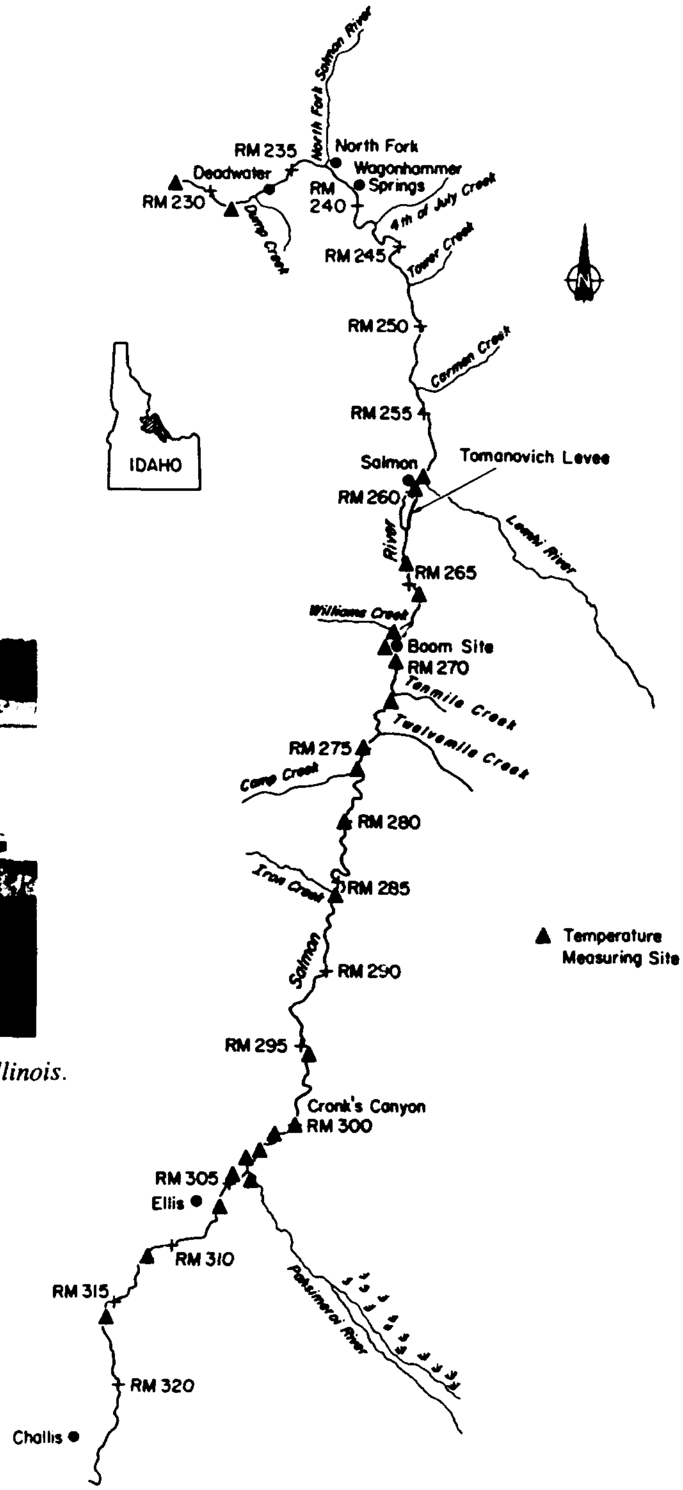


Figure 5. Upper Salmon River from Deadwater Reach to Challis, Idaho.

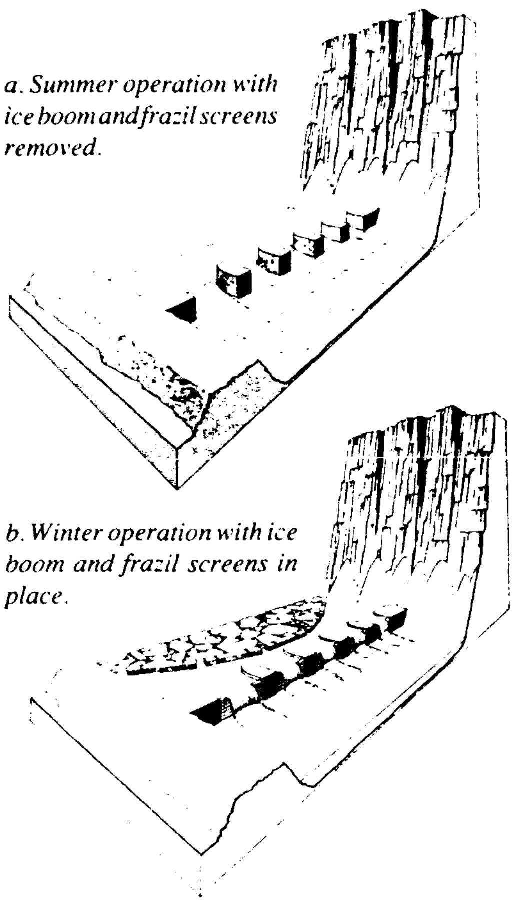


Figure 6. Artist's conception of proposed ice-control structure.

ter area (RM 233). It joins with the Snake River south of Lewiston, Idaho (RM 0).

In a typical year an ice cover begins to form in the Deadwater area at RM 233 during late November or early December. At this location the river slope has flattened out sufficiently for the ice flowing in the river to bridge across the river and initiate an ice cover. The ice generated in the upper reaches of the river collects behind this ice cover and the resulting ice jam progresses upstream quickly until the leading edge reaches RM 249 (the Big Flat area). In a mild year the river has sufficient storage for the frazil ice to prevent the cover from reaching the City of Salmon. However, during a severe winter there is more frazil ice being generated than the storage area in the river can handle, and the ice jam progresses upstream to Salmon.

The U.S. Army Engineer District, Walla Walla, and CRREL have studied the river, investigating causes of flooding and alternative methods of ice control and flood protection (Earickson and Gooch 1986). Earickson and Zufelt (1986) have stated that a stoplog or weir-type structure upstream of the City of Salmon could reduce the quantity of frazil feeding the Deadwater jam by as much as 65%. Figure 6 shows conceptual sketches of such an ice control structure.

Winter 1985–86

Testing in Salmon, Idaho, was conducted from 1–7 January 1986 at the Island Park bridge, on the left channel of the Salmon River (Fig. 7). The channel at this location is about 50 ft wide and 5 ft deep, and measured flow velocities are 5–6 ft/s for normal winter flows. The test structure was 10 ft wide and 5 ft high. We felt that, although the pooling effect would not be observed

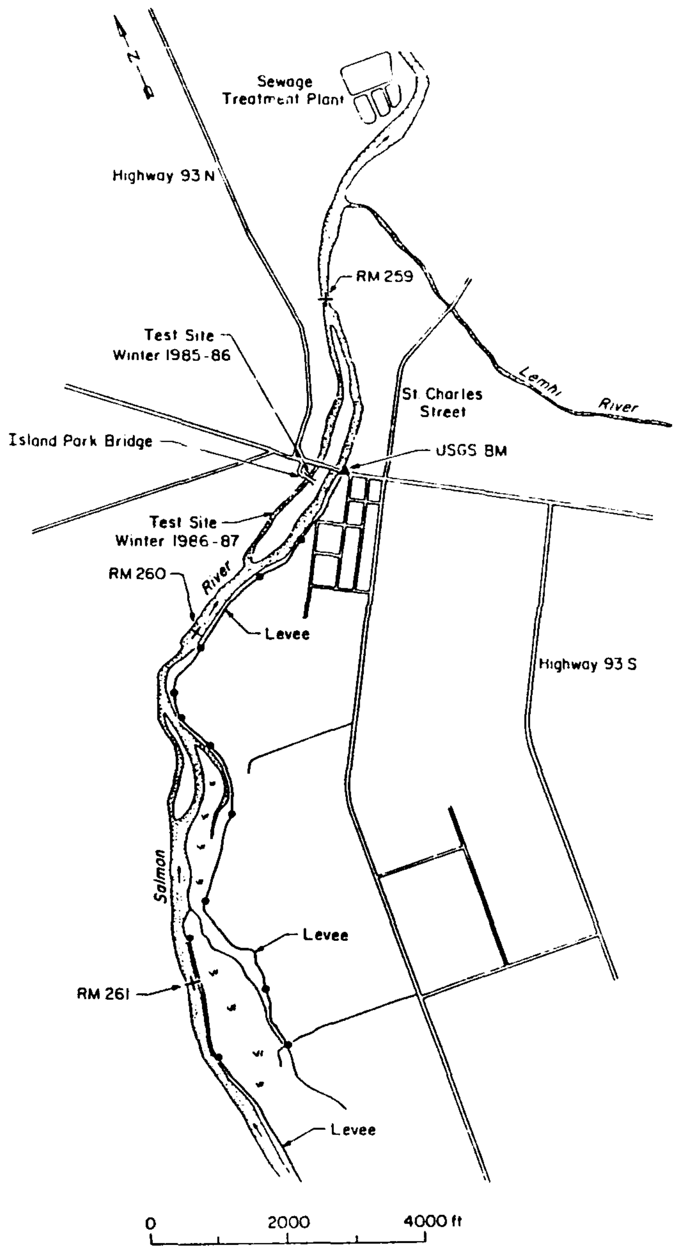


Figure 7. Location of test structures in Salmon, Idaho.

owing to the small relative size of the structure, valuable information on the clogging of different mesh sizes would be obtained. The mesh materials tested were:

1. Expanded sheet metal, 1.5- × 0.75-in. grid.
2. Chain link fence, 2.25- × 2.25-in. grid.
3. Anti-climb fence, 2- × 4-in. grid.
4. Welded concrete-reinforcing wire mesh, 6- × 6-in. grid overlapped to give 3 × 3 in.
5. Welded concrete-reinforcing wire mesh 6- × 6-in. grid.

During the test period, nighttime low temperatures were –8 to 10°F and daytime highs were 18 to 32°F. Moderately high temperatures near the end of the test period, when the anti-climb fence and the welded concrete-reinforcing wire mesh were tested, did not allow us to obtain useful results because there was no frazil being generated. Also, because of the small size of the structure compared to the stream width, most of the suspended ice flowed around it. During the test period, there was a fairly large concentration of surface frazil (on the order of 30–50% of the surface area), but it accumulated only on the expanded sheet metal screen. Figure 8 shows the accumulation of ice on the expanded sheet metal. Although not clearly shown in the photograph, most of the screen was clogged. Figure 9 shows the chain link fence fabric with little accumulation.

Figure 8. Accumulation of frazil ice on expanded sheet metal test structure.

Figure 9. Chain link fence test structure with little frazil ice accumulation.

Winter 1986–87

Test site

A new test site, located approximately 300 ft upstream of the Island Park Bridge, where the test program was run the previous year (see Fig. 7), was chosen for a full-scale test for three primary reasons.

The first reason was one of safety. If the structure worked as anticipated and made the pool 3 ft deeper, the channel on the east side of the island would have the capacity to carry the flow with no detrimental effects.

The second reason was that the city owned an old pool building on the island that had power and heat available for instrumentation. This building was also secure from vandalism.

The third reason was the availability of a large parking lot, on the top of the left bank, which was used as a staging area during final assembly of the wire mesh structure.

We obtained the channel geometry from a previous study of the river. The river is 70 ft wide with an estimated depth of 3.5 ft and a velocity of 3.5 ft/s. The river bottom consists of coarse gravel and cobbles. The cobbles have a diameter of 8–12 in.

Test structure

Design considerations. To reduce the flow velocity down to 2.0–2.3 ft/s, a head increase of 2–3 ft was needed. To obtain this head increase, a 5-ft-high structure was designed. Using a momentum approach, we computed the loads on the structure to be on the order of 770 lb/ft.

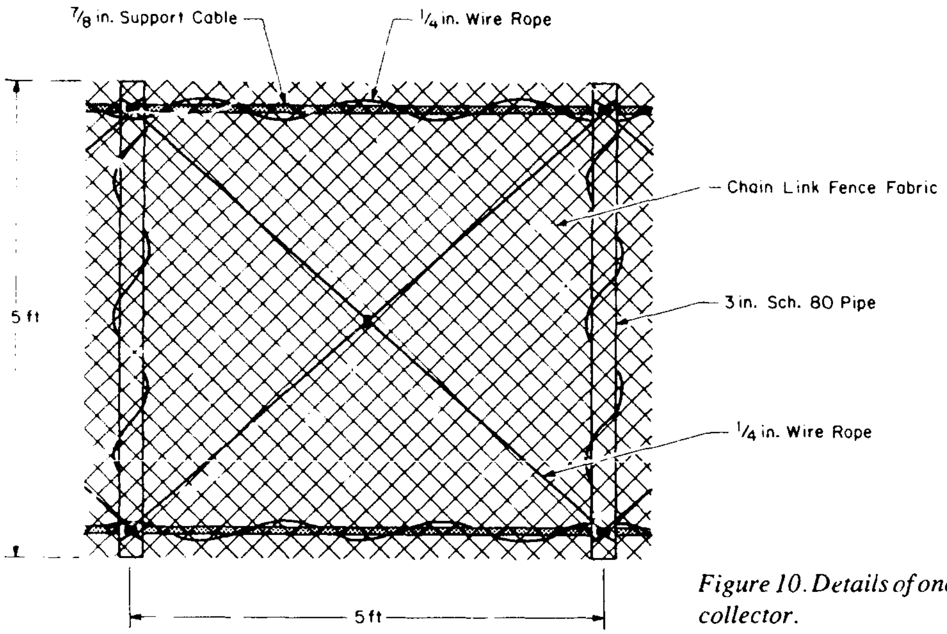


Figure 10. Details of one panel of wire mesh frazil collector.

We designed for a structure supported by a parabolic cable with a sag-to-length ratio of 0.155; we estimated the tensile load on the structure to be 51,400 lb. Deadman anchors were constructed with 2-ft diameter culvert pipes, 6 ft long, filled with concrete and buried 6–8 ft deep. A 1-in.-diameter wire rope was looped around the anchor and attached to a bridle, which in turn was attached to the wire mesh frazil collector. The two main support cables were $\frac{7}{8}$ in. in diameter with 3-in.-diameter pipes placed vertically at 5-ft centers to support the upper cable (Fig. 10).

Although the previous year's testing seemed to recommend the expanded sheet metal, chain link fence fabric was used as the wire mesh because of its flexibility and low cost. The chain link fabric was tied to the structure using $\frac{1}{4}$-in. wire rope and supported at the mid-panel with $\frac{1}{2}$-in. wire rope.

Field installation. The anchors for the structure were installed during the first week in December 1986. The wire rope spelter sockets on the ends of the main support cables were attached and the mid-panel wire ropes and the posts were fabricated during the second week in December. Final fabrication and installation of the structure was completed on 19 December.

As built, the structure consisted of the original 75-ft main structure, but included two additional 5-ft long wire rope bridles. The addition of the bridles increased the total length of the structure to 85 ft.

A wire rope was connected to the structure, rigged through a snatch block and pulled across the river with a backhoe. When the wire rope bridle reached the anchor attachment point, the bridle was shackled to the anchor. The backhoe then moved to the left bank, where enough tension was loaded onto the structure to connect the bridle to the anchor.

It was necessary to pick up the top of the structure to force it to stand upright. Once the structure was standing, the hydrodynamic load was sufficient to force the wire ropes to form the parabolic downstream shape and the structure could then stand on its own.

The air temperature at the time of installation was 32°F (0°C) and the water temperature was 33.4°F (0.8°C).

Data acquisition system

The measurements that we took during the test program consisted of the tensile load between the anchor point and the wire rope bridle at the right bank, the air and water temperatures, and the head loss across the structure.

The tension was measured using a StrainSert 100,000-lb tension link load cell, which was powered by a signal conditioner and amplifier. Air and water temperatures were measured using precision thermistors. Head losses were measured using a ruler or a survey level and rod.

The dc voltage output from the tension link load cell and the change in resistance from the two thermistors were read using a Hewlett-Packard Data Acquisition and Control Unit (Model 3421A). The data acquisition system was in turn controlled by a Hewlett-Packard Model HP-71B computer. A data acquisition package, Hewlett-Packard Model HP 834729A, which is a Read Only Memory (ROM) module, was used in the system. This data acquisition package easily allows the user to tailor the timing of acquisition. The system was programmed to record the average of a burst of five read-

ings every 10 minutes. These data were then stored on floppy disks on a Hewlett-Packard Model HP 9114B Portable Disk Drive. A single disk has the capability of storing over 2000 sets of readings.

Glass bead thermistors are used extensively when dealing with ice processes in rivers because minute temperature changes cause easily measured changes in resistance. The thermistors used have a nominal resistance of 5000–6000 Ω at 32°F (0°C), but each thermistor has to be individually calibrated. The Steinhart–Hart equation (eq 1) is then used to determine the temperature. The absolute accuracy of thermistors, using this interpolation equation, is ±0.04°F (0.02°C) when the upper and lower calibration temperatures are within 180°F (100°C) of each other (Omega 1988).

$$\frac{1}{T} = A + B \ln(R) + C(\ln R)^3 \qquad (1)$$

where T is the temperature in kelvins, R is the resistance of the thermistor in ohms, and A, B and C are coefficients to be determined from calibration at three temperatures.

The HP 3421A data acquisition unit is basically a multiplexing digital volt-ohm multimeter. The accuracy of the multimeter is a function of the resolution required, that is 3.5 to 5.5 digits, the time from calibration and the operating environment.

We used the HP 3421A multimeter in the two-wire ohm resistance mode to read the resistance of the thermistors. These measurements, at the 5.5-digit resolution, have an accuracy of 0.354%. The accuracy, near 32°F (0°C) where the resistance of the thermistor is 6700 Ω, is equivalent to 0.04°F (0.02°C). The total system accuracy is then on the order of ±0.02°F (0.04°C).

The tension link load cell and amplifier system were calibrated at 50,000 lb/V. Using the 5.5-digit mode, the accuracy of the acquisition system is 0.0181% +3 counts. This accuracy, at the maximum recorded load of 21,000 lb, is approximately 5 lb.

Sequence of events

The structure was released on 23 December, apparently by vandals, and was subsequently reinstalled on 30 December. Testing was then continued through 16 January.

Figures 11 and 12 show the measured air and water temperatures and the measured loads on the structure from 30 December through 16 January. One should note the significant water temperature fluctuation during 3–7 January. During this time the average air temperature had risen above 23°F (–5°C) and large quantities of shore ice had broken loose from upstream. Apparently, all of the suspended ice in the flow had been melted, and the incoming solar radiation, which occurs in the mountains on clear days, was able to raise the water temperature up to 33°F (0.5°C). The high loads that the structure experienced during this time were caused by the shore ice being lodged at the structure, not frazil ice being trapped. As the air began to cool off on 6 January, the water temperature once again dropped and frazil ice was formed. The load record of the structure reflects the frazil ice that was trapped by the structure. Towards the latter part of the test, the air temperature dropped below –4°F (–20°C), and the loads on the structure approached 18,000–19,000 lb.

During this time we were able to observe how the structure trapped ice (Fig. 13). The ice dam is formed at the water surface and progresses towards the bottom. As the ice dam continues to close down, the open area near the river bed experiences high flow velocities and the unprotected bed begins to be scoured. This scour prevented the upstream water level from rising as high as we anticipated.

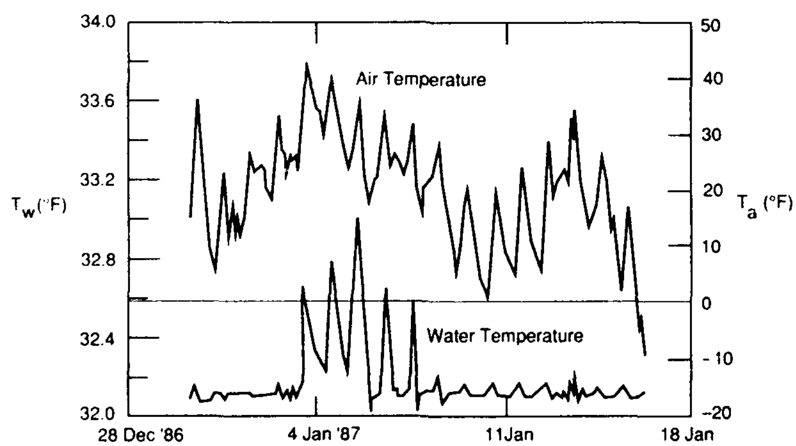


Figure 11. Measured air and water temperatures in the Salmon River in Salmon, Idaho.

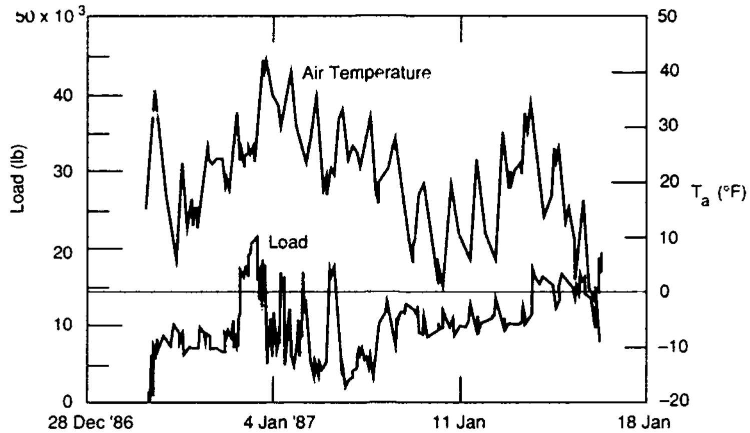


Figure 12. Measured air temperatures at Salmon, Idaho, and measured tensile loads on wire mesh frazil collector.

Figure 13. Wire mesh frazil collector with floating ice boom in the Salmon River in Salmon, Idaho.

CONCLUSIONS

Although the field tests with wire mesh frazil collectors were not as successful as hoped, this concept for frazil ice control cannot be dismissed. The use of wire mesh frazil collectors continues to show promise, especially in areas where expensive permanent structures are environmentally or economically unjustifiable. The results of the laboratory and field tests show that for this concept to be successful the following conditions must be met.

1. Bed and bank scour must be avoided either by locating the structure in a suitable area or by preparing the riverbed. Bed preparation would include leveling the bed and placement of armoring, whether it be rip-rap, gabions, or concrete paving.

2. The screen must remain as nearly vertical as possible to prevent the ice accumulation from washing off the face of the screen. Once again, leveling the bed will help to keep the structure vertical.

3. The screen structure should be located in a river reach where active frazil is generated so that the ice dam will form quickly.

4. The screen structure should extend above the original water surface to assist in retaining the ice cover.

5. An ice boom is useful in maintaining the integrity of the ice cover.

FUTURE RESEARCH

Future research will include laboratory tests to determine the extent of bed protection that will be required to prevent bed scour as the flow accelerates beneath the ice dam. This test program will consist of determining velocity profiles in a rigid-bed flume as the flow area is reduced. A moveable bed model will then be used with different levels of modeled scour protection to verify the effectiveness of this protection.

In addition to this testing, a technique must be developed to measure the structural integrity of a frazil ice accumulation. It became apparent from the limited field tests that the structure would work best in an area where active frazil is being generated, but at the same time, the load imposed on the ice accumulation tends to push it through the structure. This implies that the ice accumulation must have enough shear strength to prevent this ice failure. A device to measure the shear strength of frazil ice has been designed with this testing in mind.

When the additional laboratory testing is completed, a prototype structure should be built with appropriate bed protection to determine the effectiveness of the structure. At this time we will test different meshes again to determine the most cost-effective choice.

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Frazil ice jams on rivers cause problems that range from slowing commercial river traffic to widespread flooding. Through the years, one of the accepted techniques of controlling frazil ice jams has been to retain the frazil ice in a location where it will not harm the environment using dams or weirs. In the interest of developing an inexpensive ice control structure, a series of laboratory and field tests were conducted using different wire mesh structures as a dam to determine which type of wire mesh best retains ice and what the optimum orientation of that mesh should be. A material such as chain link fence fabric would collect and retain the ice, but proper bed preparation must be done to prevent bed scour. Further study is required to determine the optimum mesh size. Keywords: Ice/accumulation; Dams, weirs; Winter/floating water traffic/ [illegible]; [illegible]/erosion; Flood control. [illegible]

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